

Effects of modified gravity on the turnaround radius in cosmology

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Abstract

© 2018 American Physical Society. We revisit the concept of turnaround radius in cosmology, in the context of modified gravity. While preliminary analyses were limited to scalar-tensor/ $F(R)$ gravity, we extend the definition and the study of this quantity to a much broader class of theories including also quantum R^2 gravity. The turnaround radius is computed in terms of the parameters of the theory, and it is shown that a deviation not larger than 10% of this quantity from its value in Einstein's theory could constrain the model parameters and even rule out some current theories.

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References

- [1] I. L. Buchbinder, S. D. Odintsov, and I. L. Shapiro, *Effective Action in Quantum Gravity* (IOP, Bristol, UK, 1992).
- [2] C. G. Callan, Jr., E. J. Martinec, M. J. Perry, and D. Friedan, *Nucl. Phys. B* 262, 593 (1985). NUPBBO 0550-3213 10.1016/0550-3213(85)90506-1
- [3] E. S. Fradkin and A. A. Tseytlin, *Nucl. Phys. B* 261, 1 (1985); NUPBBO 0550-3213 10.1016/0550-3213(85)9055-0
- [4] E. S. Fradkin and A. A. Tseytlin *Nucl. Phys. B* 269, 745(E) (1986). NUPBBO 0550-3213 10.1016/0550-3213(86)90522-5
- [5] S. Capozziello and M. De Laurentis, *Phys. Rep.* 509, 167 (2011). PRPLCM 0370-1573 10.1016/j.physrep.2011.09.003
- [6] Y. F. Cai, S. Capozziello, M. De Laurentis, and E. N. Saridakis, *Rep. Prog. Phys.* 79, 106901 (2016). RPPHAG 0034-4885 10.1088/0034-4885/79/10/106901
- [7] S. Nojiri and S. D. Odintsov, *Int. J. Geom. Methods Mod. Phys.* 04, 115 (2007). 0219-8878 10.1142/S0219887807001928
- [8] T. P. Sotiriou and V. Faraoni, *Rev. Mod. Phys.* 82, 451 (2010). RMPHAT 0034-6861 10.1103/RevModPhys.82.451
- [9] S. Nojiri and S. D. Odintsov, *Phys. Rep.* 505, 59 (2011). PRPLCM 0370-1573 10.1016/j.physrep.2011.04.001
- [10] S. Nojiri, S. D. Odintsov, and V. K. Oikonomou, *Phys. Rep.* 692, 1 (2017). PRPLCM 0370-1573 10.1016/j.physrep.2017.06.001
- [11] T. Clifton, P. G. Ferreira, A. Padilla, and C. Skordis, *Phys. Rep.* 513, 1 (2012). PRPLCM 0370-1573 10.1016/j.physrep.2012.01.001
- [12] K. Bamba, S. Capozziello, S. Nojiri, and S. D. Odintsov, *Astrophys. Space Sci.* 342, 155 (2012). APSSBE 0004-640X 10.1007/s10509-012-1181-8
- [13] S. Capozziello, S. Carloni, and A. Troisi, *Recent Res. Dev. Astron. Astrophys.* 1, 625 (2003). AAEJAF 0004-6361
- [14] S. Nojiri and S. D. Odintsov, *Phys. Rev. D* 68, 123512 (2003). PRVDAQ 0556-2821 10.1103/PhysRevD.68.123512
- [15] T. Baker, D. Psaltis, and C. Skordis, *Astrophys. J.* 802, 63 (2015). ASJOAB 1538-4357 10.1088/0004-637X/802/1/63

- [16] Z. Stuchlik, Bull. Astron. Inst. Czech. 34, 129 (1983). BAICAP 0004-6248
- [17] Z. Stuchlik and S. Hledik, Phys. Rev. D 60, 044006 (1999). PRVDAQ 0556-2821 10.1103/PhysRevD.60.044006
- [18] Z. Stuchlik, P. Slany, and S. Hledik, Astron. Astrophys. 363, 425 (2000). AAEJAF 0004-6361
- [19] Z. Stuchlik, Mod. Phys. Lett. A 20, 561 (2005). MPLAEQ 0217-7323 10.1142/S0217732305016865
- [20] M. Mizony and M. Lachieze-Rey, Astron. Astrophys. 434, 45 (2005). AAEJAF 0004-6361 10.1051/0004-6361:20042195
- [21] Z. Stuchlik and J. Schee, J. Cosmol. Astropart. Phys. 09 (2011) 018. JCAPBP 1475-7516 10.1088/1475-7516/2011/09/018
- [22] Z. Roupas, M. Axenides, G. Georgiou, and E. N. Saridakis, Phys. Rev. D 89, 083002 (2014). PRVDAQ 1550-7998 10.1103/PhysRevD.89.083002
- [23] B. C. Nolan, Classical Quantum Gravity 31, 235008 (2014). CQGRDG 0264-9381 10.1088/0264-9381/31/23/235008
- [24] M. T. Busha, F. C. Adams, R. H. Wechsler, and A. E. Evrard, Astrophys. J. 596, 713 (2003). ASJOAB 1538-4357 10.1086/378043
- [25] V. Pavlidou and T. N. Tomaras, J. Cosmol. Astropart. Phys. 09 (2014) 020. JCAPBP 1475-7516 10.1088/1475-7516/2014/09/020
- [26] V. Pavlidou, N. Tetradis, and T. N. Tomaras, J. Cosmol. Astropart. Phys. 05 (2014) 017. JCAPBP 1475-7516 10.1088/1475-7516/2014/05/017
- [27] V. Faraoni, Proc. Sci., EPS-HEP2017 (2017) 037, <https://pos.sissa.it/314/>.
- [28] V. Faraoni, M. Lapierre-Léonard, and A. Prain, J. Cosmol. Astropart. Phys. 10 (2015) 013. JCAPBP 1475-7516 10.1088/1475-7516/2015/10/013
- [29] S. Hawking, J. Math. Phys. (N.Y.) 9, 598 (1968). JMAPAQ 0022-2488 10.1063/1.1664615
- [30] S. A. Hayward, Phys. Rev. D 49, 831 (1994). PRVDAQ 0556-2821 10.1103/PhysRevD.49.831
- [31] S. A. Hayward, Phys. Rev. D 53, 1938 (1996). PRVDAQ 0556-2821 10.1103/PhysRevD.53.1938
- [32] L. B. Szabados, Living Rev. Relativity 12, 4 (2009). 1433-8351 10.12942/lrr-2009-4
- [33] M. Lapierre-Léonard, V. Faraoni, and F. Hammad, Phys. Rev. D 96, 083525 (2017). PRVDAQ 2470-0010 10.1103/PhysRevD.96.083525
- [34] V. Faraoni, Phys. Dark Universe 11, 11 (2016). PDUHA3 2212-6864 10.1016/j.dark.2015.11.001
- [35] S. Capozziello, K. F. Dialektopoulos, and O. Luongo, arXiv:1805.01233.
- [36] R. C. C. Lopes, R. Voivodic, L. R. Abramo, and L. Sodré, arXiv:1805.09918.
- [37] S. Bhattacharya, K. F. Dialektopoulos, A. E. Romano, C. Skordis, and T. N. Tomaras, J. Cosmol. Astropart. Phys. 07 (2017) 018. JCAPBP 1475-7516 10.1088/1475-7516/2017/07/018
- [38] R. G. Cai, L. M. Cao, Y. P. Hu, and N. Ohta, Phys. Rev. D 80, 104016 (2009). PRVDAQ 1550-7998 10.1103/PhysRevD.80.104016
- [39] R. G. Cai, L. M. Cao, Y. P. Hu, and S. P. Kim, Phys. Rev. D 78, 124012 (2008). PRVDAQ 1550-7998 10.1103/PhysRevD.78.124012
- [40] S. F. Wu, B. Wang, and G. H. Yang, Nucl. Phys. B 799, 330 (2008). NUPBBO 0550-3213 10.1016/j.nuclphysb.2008.01.013
- [41] G. Cognola, O. Gorbunova, L. Sebastiani, and S. Zerbini, Phys. Rev. D 84, 023515 (2011). PRVDAQ 1550-7998 10.1103/PhysRevD.84.023515
- [42] V. Faraoni, Classical Quantum Gravity 33, 015007 (2016). CQGRDG 0264-9381 10.1088/0264-9381/33/1/015007
- [43] F. Hammad, Classical Quantum Gravity 33, 235016 (2016). CQGRDG 0264-9381 10.1088/0264-9381/33/23/235016
- [44] J. Lee, S. Kim, and S. C. Rey, Astrophys. J. 815, 43 (2015). ASJOAB 1538-4357 10.1088/0004-637X/815/1/43
- [45] J. Lee, Astrophys. J. 832, 123 (2016). ASJOAB 1538-4357 10.3847/0004-637X/832/2/123
- [46] J. Lee and G. Yepes, Astrophys. J. 832, 185 (2016). ASJOAB 1538-4357 10.3847/0004-637X/832/2/185
- [47] J. Lee and B. Li, Astrophys. J. 842, 2 (2017). ASJOAB 1538-4357 10.3847/1538-4357/aa706f
- [48] J. Lee, Astrophys. J. 856, 57 (2018). ASJOAB 1538-4357 10.3847/1538-4357/aab358
- [49] R. M. Wald, General Relativity (Chicago University Press, Chicago, 1984).
- [50] R. R. Caldwell, M. Kamionkowski, and N. N. Weinberg, Phys. Rev. Lett. 91, 071301 (2003). PRLTAO 0031-9007 10.1103/PhysRevLett.91.071301
- [51] P. H. Frampton, K. J. Ludwick, and R. J. Scherrer, Phys. Rev. D 84, 063003 (2011). PRVDAQ 1550-7998 10.1103/PhysRevD.84.063003
- [52] P. H. Frampton, K. J. Ludwick, S. Nojiri, S. D. Odintsov, and R. J. Scherrer, Phys. Lett. B 708, 204 (2012). PYLBAJ 0370-2693 10.1016/j.physletb.2012.01.048

- [53] D. N. Vollick, Phys. Rev. D 76, 124001 (2007). PRVDAQ 1550-7998 10.1103/PhysRevD.76.124001
- [54] E. Pechlaner and R. Sexl, Commun. Math. Phys. 2, 165 (1966). CMPHAY 0010-3616 10.1007/BF01773351
- [55] M. Ferraris, M. Francaviglia, and G. Magnano, Classical Quantum Gravity 5, L95 (1988). CQGRDG 0264-9381 10.1088/0264-9381/5/6/002
- [56] T. P. Sotiriou, Classical Quantum Gravity 23, 5117 (2006). CQGRDG 0264-9381 10.1088/0264-9381/23/17/003
- [57] A. M. Nzioki, S. Carloni, R. Goswami, and P. K. S. Dunsby, Phys. Rev. D 81, 084028 (2010). PRVDAQ 1550-7998 10.1103/PhysRevD.81.084028
- [58] T. Clifton and J. D. Barrow, Phys. Rev. D 72, 123003 (2005). PRVDAQ 1550-7998 10.1103/PhysRevD.72.123003
- [59] T. Clifton and J. D. Barrow, Classical Quantum Gravity 23, 2951 (2006). CQGRDG 0264-9381 10.1088/0264-9381/23/9/011
- [60] J. D. Barrow and T. Clifton, Classical Quantum Gravity 23, L1 (2006). CQGRDG 0264-9381 10.1088/0264-9381/23/1/L01
- [61] A. F. Zakharov, A. A. Nucita, F. De Paolis, and G. Ingrosso, Phys. Rev. D 74, 107101 (2006). PRVDAQ 1550-7998 10.1103/PhysRevD.74.107101
- [62] V. Faraoni, Phys. Rev. D 74, 104017 (2006). PRVDAQ 1550-7998 10.1103/PhysRevD.74.104017
- [63] V. Faraoni, Phys. Rev. D 75, 067302 (2007). PRVDAQ 1550-7998 10.1103/PhysRevD.75.067302
- [64] S. Nojiri and S. D. Odintsov, Phys. Rev. D 66, 044012 (2002). PRVDAQ 0556-2821 10.1103/PhysRevD.66.044012
- [65] H. Lu and C. N. Pope, Phys. Rev. Lett. 106, 181302 (2011). PRLTAO 0031-9007 10.1103/PhysRevLett.106.181302
- [66] R. Myrzakulov, S. Odintsov, and L. Sebastiani, Phys. Rev. D 91, 083529 (2015). PRVDAQ 1550-7998 10.1103/PhysRevD.91.083529
- [67] E. Berti, Classical Quantum Gravity 32, 243001 (2015). CQGRDG 0264-9381 10.1088/0264-9381/32/24/243001
- [68] D. Psaltis and F. Özel, Phys. Today 71, 70 (2018). PHTOAD 0031-9228 10.1063/PT.3.3906
- [69] D. Psaltis, F. Özel, C. K. Chan, and D. P. Marrone, Astrophys. J. 814, 115 (2015). ASJOAB 1538-4357 10.1088/0004-637X/814/2/115